AVOIDING HEALTH RISKS FROM DRINKING WATER: THEORY AND MOSCOW SURVEY RESULTS

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1. INTRODUCTION

For environmental and health policy, it is useful to distinguish between *unilateral* and *bilateral* risks management problems (see, e.g., Shibata and Winrich, 1983). With unilateral risks, the actions of Group A create some initial risk to Group B, and Group B is not able to alter the amount of risk it receives. In this case, risk management must focus only on Group A (e.g., the polluter). With bilateral risks, the actions of Group A create some initial risk, but Group B has some ability to alter the amount of risk it receives by undertaking various measures. Thus, with bilateral risks, policy can focus on the actions of both Group A and Group B.

Health risks from tap water are a good example of bilateral risks.[1] Water quality at the tap creates some level of health risk in water. But before consuming tap water, based on their perceptions of quality, households can undertake various measures to improve the quality of the water. These measures are often called avoidance measures or averting actions, while the money spent on such actions is often called defensive expenditures. If avoidance measures are inexpensive, widely available, and widely used, actual health risks from water consumed may be substantially different from apparent risks at the tap. In such cases, residents may prefer to continue to make their own avoidance decisions rather than paying higher user charges to finance investments in water treatment and distribution as an alternative approach to managing health risks.

In Russia, casual observation suggests that many households boil water, settle water in pans for some period (e.g. overnight) before consuming, filter water, and buy bottled water.[2] To date, there has been little empirical analysis of such avoidance behavior, which is surprising given concerns over health risks from tap water and the number of cities that are financing or attempting to finance water infrastructure improvement projects designed in part to improve quality at the tap.

Based on a recently completed survey of 615 households in Moscow, the purpose of this paper is to begin to investigate the types and amounts of avoidance measures that are used by households in Moscow to adjust drinking water quality. This example from Moscow can also be used as a guide for future studies in other cities in Russia to evaluate opinions of quality, avoidance measures, and citizens' willingness to support public infrastructure projects designed to improve water supply.[3]

The paper is organized as follows. As background on the topic, Section 2 develops a simple economic framework based on household production theory that can be used to analyze avoidance behavior.[4] Section 2 identifies an equation that describes avoidance behavior and provides three simple testable hypotheses regarding empirical form. As a result, while any survey can ask about opinions, the model in Section 2 can be used to evaluate the quality of the responses. If the survey responses are consistent to some degree with economic theory, there is additional evidence that the survey was able to provide reasonable information. Section 2 also shows how actual avoidance expenditures are related to

[1] Chronic health risks from air pollution are a good example of unilateral risks, except to the extent that people can physically move out of an area to avoid risks from ambient air.

[2] Another avoidance measure is to consume only water from the cold water supply and not to consume water from the district hot water system.

[3] The logical next step would be to assess directly citizens' willingness to accept changed water tariffs to support specific public infrastructure projects using a contingent valuation approach.

[4] See, for example, Becker (1981) and Singh, Squire, and Strauss (1986).

willingness to pay for water quality improvements.[5] Section 3 discusses the data obtained as part of the Moscow Drinking Water Survey. After a description of survey method, information is provided on the types and frequency of use of different avoidance measures and on opinions of water quantity (consistency of supply) and water quality. In Section 4, based on a binomial logit statistical framework as an approximation to the theoretical framework in Section 2, we investigate how choices of avoidance measures are related to respondents' opinions of their water quality and service and other socio-economic characteristics (location in city, children in household, education, income, etc.).[6] Section 5 concludes.

We want to emphasize at the outset that the main purpose of this analysis was to determine if avoidance measures are used in Moscow, and to what degree, to affect water quality prior to consumption. Survey results show that this is clearly the case: over 88 percent of the sample boil water regularly due to concerns about water quality; 23 percent filter water regularly; over 30 percent settle water regularly; and about 13 percent buy bottled water regularly. On the other hand, residents are generally content with their <u>cold</u> water supply and quality of delivery. These two results are not that surprising: consistency of cold water supply is good in Moscow and water prices are very cheap, while people have several low-cost options to improve quality from the tap prior to consumption if they so desire.

2. A SIMPLE HOUSEHOLD MODEL OF AVOIDANCE BEHAVIOR

The purpose of this section is to develop a simple economic framework for understanding avoidance behavior. The basic idea is that a household 'produces' drinking water, what Bartik (1988) calls the "quality of its personal environment", based on water coming into the apartment at the tap along with any measures taken to adjust quality. Household production theory provides a reasonable analytical framework for investigating avoidance behavior (e.g., Becker, 1981, Singh, Squire, and Strauss, 1986).

2.1 The Model

For notation, let 'x' represent the household's *perception/opinion* of the quality of water coming into the apartment at the tap. We emphasize the word perception because households never have clear, objective facts on water quality.[7] For example, in an interview with an important ecological newspaper "Green

[5] This topic has been addressed in previous literature (see, e.g., Shibata and Winrich, 1993; Harford, 1984; Courant and Porter, 1981; Harrington and Portney, 1987; and Bartik, 1988). Section 2 highlights what is important in the previous literature for this analysis and provides some additional results of importance here that do not exist in the previous literature.

[6] Of course the obvious question to ask is: what is the quality of Moscow water? Unfortunately, there is not an objective answer to this question and there is unlikely to be such an answer any time soon for several reasons. The public utility, responsible for water supply [Mosvodokanal (MVK)]and the city's Committee of State Sanitary and Epidemiological Surveillance say that Moscow drinking water meets all Russian and international standards. However, MVK does not provide public access to its water monitoring data for the public to evaluate. Given the lack of credibility of some public institutions in Russia, Moscovites do not necessarily believe the press releases of MVK. At the same time, water filter companies continue to advertise potential problems that can exist in public water supplies as a way of increasing demand for their product. During the first half of 1996, the Harvard Institute for International Development (HIID) attempted to convene a team of Russian and American scientists, along with MVK staff, to undertake an objective quantitative risk assessment at several stages of the water distribution system (intake, after treatment plant, in the distribution network, and at the tap). After initially agreeing to support such analysis, MVK decided not to participate in the study and did not provide access to its water quality monitoring data.

[7] People can taste, smell, feel, and see water. People also receive various types of information on tap water quality provided, for example, by the water provider and city health authorities. But it should be recognized that people take such information into account in their own way. While an interesting issue for public policy research, how

World," Dr. N. Filatov, the Senior State Doctor for Sanitation and Hygiene, states that Moscow drinking water is clear and Moscovites can drink it directly from the tap, but it is "better, of course, to settle or boil tap water before consumption" (Ardabatskaya and Soboleva, 1997). One can only wonder what such mixed signals mean for residents in Moscow.[8]

Let 'a' represent avoidance measures used by the household to improve tap water quality, and let p represent the price of such measures. Let 'z' represent other consumption goods purchased at price c. In general, there are several possible measures and other consumption items, in which case 'a' and 'z' represent vectors with p and c being the corresponding vectors of prices.[9] A household cannot spend more than its income, denoted as I, so that pa + cz # I. Based on perceptions x and avoidance measures a, the household produces water of quality y, where y = f(a,x) is the household's production function. The function f is increasing in x and a (i.e the first partial derivatives fx>0 and fa>0). There is substitution between x and a, so that $da/dx_{\, y = \text{constant}} = -fx/fa < 0$. Note that if there is perfect substitution, then $da/dx_{\, y = \text{constant}} = -1$. And last, let U = U(y,z ;β) represent the household's utility function, where 'β' represents characteristics of the household other than income, such as family size, apartment location, education, etc.[10]

Based on this notation, the household's problem of choosing avoidance measures can be modeled as:

$$\begin{gathered} \max_{y,z} U(y,z;\beta) \\ s.t.\ E(p,y,x) + cz \leq I \\ where E(p,y,x) \equiv \min_a pa \ \ s.t.\ \ y = f(a,x) \end{gathered} \tag{1}$$

In (1), the overall problem is separated into two steps. First, the expenditure function E(p,y,x) is the minimum expenditure on avoidance measures needed to obtain a level of water quality y given initial quality x. And second, given the expenditure function, the optimal level of y and z are chosen, defined here as y^* and z^*, to maximize overall utility subject to the budget constraint.[11]

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perceptions are formed and how information is used in the process is not the purpose of this research and is not addressed in this theoretical analysis or in the Moscow survey.

8 Such unclear information, along with advertising campaigns by filter and bottled water companies, has probably contributed to the growing use of filters and bottled water in Russia. Basic market access, income growth, and preferences are of course also involved.

9 For most measures, the market price is an adequate definition of cost. In some situations, such as letting water settle overnight, a measure essentially has no cost. In other situations, such as boiling water using a wood stove, costs would include fuelwood costs and time. In Moscow, where natural gas is a main cooking fuel and is very inexpensive, boiling water has little cost as well (a little time, probably of the retired parent living in the apartment).

10 It could also be possible to include the vector β directly into the production function, so that y = f(a;x,β). When avoidance measures a represents a vector of avoidance options, then there can be substitution across individual avoidance options as well (i.e. boiling water and buying bottled water).

11 The formulation in (1) is a simple variation on different models of defensive expenditures (e.g, Bartik, 1988; Courant and Porter, 1981; Berking and Stanley, 1986; Harford, 1984; Harrington and Portney, 1987; and Shibata and Winrich; 1983). Since this earlier literature is focused on defensive expenditures, the expenditure minimization problem in problem (1) is not explicitly addressed in earlier literature. For example, the Bartik model is exactly the model outline in problem (1) when c = 1 and prices p of avoidance measures are ignored, in which case the avoidance expenditure function is just written as E(y,x). As is shown in this section, this level of abstraction eliminates some useful detail in the model that can be exploited in the analysis of avoidance behavior.

2.2 The Optimal Level of Avoidance

The solution to the problem in (1) implies an indirect utility function that can be written as $V^x = V(p, I; x, \beta)$. Using the envelope theorem, the household's optimal choice of avoidance, a^*, can be written as:

$$a^* = -\frac{\partial V / \partial p}{\partial V / \partial I} = \frac{\partial E}{\partial p} = a^e[p,x,y^*(p,c,I,x,\beta)] \tag{2}$$

where the function a^e is the expenditure minimizing level of avoidance from problem (1) evaluated at the optimal level of water quality y^* from problem (1). While not shown directly in the previous literature on defensive expenditures, equation (2) is very useful in understanding the relationship between defensive expenditures and willingness to pay for improved environmental quality.

From equation (2), five types of variables are in general related to avoidance behavior: the price of avoidance represented by p; other prices represented by c; income represented by I; the household's opinions of tap water represented by x; and general characteristics of the household represented by β. All the basic results of consumer theory with respect to prices and income, such as homogeneity and the Slutsky matrix, hold for this model (see Varian).[12] Thus, as usual:

$$\frac{\partial a^*}{\partial p} \leq 0 \;\; and \;\; \frac{\partial a^*}{\partial I} \geq 0 \;\; if \; normal \; good \tag{3}$$

All else constant, higher prices of avoidance measures imply lower levels of avoidance for normal goods (higher income implies higher consumption). It is possible, however, that some avoidance measures are inferior goods so that income effects are negative. This issue is discussed in more detail in Section IV in relation to boiling water.

A more complicated issue to investigate is the relationship between basic initial quality x and the optimal level of avoidance, a^*. Using equation (2) and differentiating with respect to x yields:

$$\frac{\partial a^*}{\partial x} = \frac{\partial a^e}{\partial x}\bigg|_{y^* constant} + \frac{\partial a^e}{\partial y}\frac{\partial y^*}{\partial x} \tag{4}$$

The sign of (4) depends on two main terms: the substitution effect and the final quality effect. The first term in (4), the substitution effect, is negative directly from the structure of the household's water production function because $Ma^e/Mx*_{y\ constant} = -fx/fa < 0$. The second term is the final quality effect, which shows how higher x also affects the final level of household produced water quality, which in turn affects avoidance behavior. It is easy to show from the structure of the avoidance production function that
$Ma^e/My > 0$.[13]

Thus, the sign of the 'basic quality' effect in (4) depends on the sign of My^*/Mx. As far as we know, the previous literature does not explicitly analyze the sign of this term. Harrington and Portney (1987)

[12] The expenditure function defined in (1) is not the same as the 'expenditure' function dual to the utility function that is used to define the Slutsky matrix.

[13] Holding x constant, more a is needed to obtain more y.

discuss this term but do not identify its sign, and the rest of the defensive expenditure literature does not discuss the term.[14] However, for environmental and health policy makers, it is of interest to know if final health risks (y^*) are improving if the basic water quality (x) is improving, taking into account all other changes that the household makes due to changes in x (i.e. changes in a^* and z^*).

To determine the sign of My^*/Mx, it is necessary to take the total differential of the three first-order conditions to problem (1) with respect to y,z, the multiplier on the income constraint, and x, and then use Cramer's Rule to solve for the derivative.[15] After some tedious algebra, this process shows that $My^*/Mx > 0$ when $M^2U/MyMz \exists 0$, and otherwise the sign of (4) could be positive or negative.[16] As it turns out, it is reasonable to assume that $M^2U/MyMz \exists 0$. For example, as shown in Varian (p. 135), this assumption is needed to assure that y and z are normal goods (more income, more y and z).

In sum, the substitution effect is always negative, the final quality effect is always positive, and it is not clear if there is more or less avoidance as basic quality increases (the sign of (4) can be positive or negative).[17] Both signs could be reasonable depending on the avoidance measure being addressed. For example, consider filtering. When water is very bad quality (maybe because of biological concerns), filtering technologies may not work adequately and households would need to boil or buy bottled water. But if quality were improved, especially in relation to biological risks, the filtering technologies may begin to work well enough and households could now use filtering more often and perhaps use less boiling and buying bottled water. In this example, the sign of (4) is positive for filtering and negative for boiling water and buying bottled water.

Thus, the structure of the underlying production function $y = f(a,x)$ drives the sign of the substitution effect. Especially for this case of drinking water quality, where there can be multiple health concerns from tap water (microbes, viruses, lead, other heavy metals, etc.) and multiple avoidance measures, future research should investigate more precisely the underlying structure of possible multiple input and output avoidance technologies.

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[14] The term shows up in equation (5) in Bartik (1988) but is not analyzed. The term is not discussed in Harford (1984) or Courant and Porter (1981).

[15] It is necessary to be clear about the sign of the determinant of the bordered Hessian for problem (1), which is positive in this case. As a side note, the second-order conditions for an optimum cannot be used to sign the determinant of the bordered Hessian; second-order conditions are just related to principle minors (see, e.g., Intrilligator for more details).

[16] For reference, this derivative is $My^*/Mx = M/N$, where

$N = 2cE_yU_{zy} - U_{zz}E_y^2 - cc(U_{yy} - \lambda E_{yy}) > 0$ is the determinant of the bordered Hessian for problem (1), $M = -cE_xU_{zy} + U_{zz}E_yE_x - cc\lambda E_{yx} > 0$ and subscripts denote partial derivatives. All of the terms can be easily signed directly from the indirect objective function, the direct utility function, the expenditure function, and the production function (using the envelope theorem when appropriate), except for the term $E_{yx} = M\lambda^e/M\,x$, where λ^e is the multiplier on the quality constraint in the expenditure function in problem (1). Using the same Cramer's rule process for the first-order conditions of the expenditure function, it is possible to show that $E_{yx} = M\lambda^e/M\,x < 0$, which intuitively makes sense because the constraint is less costly as x increases.

[17] Harrington and Portney (1987, p. 107 and 111) discuss the possibility that final quality could decrease as basic quality increases (in their model $dS/dP < 0$, where P is pollution and S is sick days). They do not directly derive the derivative, but think that is unlikely. Their initial intuition is correct here, and final quality must increase as basic quality increases.

The avoidance equation (2) along with the optimal demand for other goods z^* can be estimated using multivariate regression methods.[18] The results in (3) and (4) provide testable hypotheses regarding avoidance behavior. However, the exact regression approach will have to vary depending on the nature of the data (time series, cross section, panel data). These econometric issues will be discussed in Section IV.

2.3 Avoidance Expenditures and Willingness to Pay for Improved Tap Water Quality

Before moving to the discussion of the Moscow survey and econometric results, it is noted here how the defensive expenditure literature uses this framework to examine how actual avoidance behavior, as measured by a^*, is related to household willingness to pay for improved water quality improvements. From (2) and (1), actual avoidance expenditures, pa^*, show how much the household actually pays to change its water quality from x to $y^* = f(a^*, x)$. Thus, although y^* is not observable directly, observed avoidance expenditures provide direct information on the amount households pay for water quality improvements <u>beyond</u> their initial level x.

The literature on defensive expenditures focuses on a different question; namely how much households are willing to pay for changed water quality at the tap (a change in basic quality from x to x+x' in problem (1)).[19] The change in avoidance expenditures induced by an increase in basic quality (as identified in (4)) can be related to willingness to pay for the basic quality improvement as follows.[20] First, let W.P. represent the maximum willingness to pay for the quality improvement, which can be defined as $V^x = V(p, c, I - W.P.; x+x', \beta)$, where V^x is the original utility level associated with the solution to problem (1). From this relationship, holding the initial utility level V^x constant, the implicit function theorem can be used to show that:

$$\frac{\partial WTP}{\partial x'} = \frac{\partial V / \partial x'}{\partial V / \partial I} \qquad (5)$$

The expression in (5) shows the willingness to pay for changes in water quality from the initial level x to the new level x+x' from the tap (a measure of compensating variation since utility is held constant at the initial level).[21]

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[18] In a time series context, (3) implies that the use of avoidance measures should increase as such measures become less expensive, income grows, and perceptions of quality declines.

[19] In Russia, depending upon a city's water infrastructure, there are two different ways to ask this question: (a) what is willingness to pay for an improvement in water quality from x to x+x', where x' represents an improvement; and (b) what is the willingness to pay to <u>avoid</u> a decline in water quality from x to x-x', where -x' represents the decline in quality. Question (a) is probably more relevant for cities like Moscow where basic water infrastructure is in reasonably good shape, while question (b) is more appropriate for other cities in Russia where water infrastructure is crumbling.

[20] To relate defensive expenditures to willingness to pay for improved basic quality, it is necessary to remember that an increase in tap water quality from x to x+x' in problem (1) will induce changes in a^* from (2) as well as z^*, which in turn will alter the final level of water quality produced by the household y^* and the final utility level V^x. It is easy to show from problem (1) that household utility increases when basic quality increases from x to x+x'. Thus, to make sure there is no confusion, households are better off when basic quality x increases.

[21] A contingent valuation approach could be used to acquire data to estimate (5) directly. See Malzubris, Senkane, and Ready (1997) for a recent contingent valuation study of willingness to pay for improved tap water quality in Sigulda, Latvia.

Willingness to pay in (5) can be directly linked to avoidance expenditures in three steps. First, from the definition of the indirect utility function V from (1) and using the envelope theorem, it is easy to show that:

$$\frac{\partial V}{\partial x'} = \frac{\partial U}{\partial y}\frac{\partial y}{\partial x'}\bigg|_{a^* \text{ constant}} \; and \; \frac{\partial V}{\partial I} = \lambda \tag{6}$$

where all terms in (6) are positive, $\lambda > 0$ is the shadow value on the income constraint in problem (1), and all functions are evaluated at the optimum in (1). Second, the first-order condition for the choice of a in problem one can be rearranged as:

$$\frac{\partial U}{\partial y} = \frac{\lambda p}{\partial y / \partial a} \tag{7}$$

where all functions are evaluated at optimal levels from (1). And third, using the results in (6) and (7), the expression in (5) can be rearranged to yield:

$$\frac{\partial WTP}{\partial x'} = p\left[\frac{(\partial y^* / \partial x)\big|_{a^* \text{ constant}}}{\partial y^* / \partial a}\right] = -p\frac{\partial a^e}{\partial x} > 0 \tag{8}$$

where the production function y=f(a,x) is evaluated at the initial optimal choice a^* to define y^* in (8) and a^e is the expenditure minimizing level of avoidance from (1).[22] From (8), WTP for better basic water quality from x to x+x' is the same as reduced avoidance expenditures <u>holding final quality y^* constant</u>.[23] This result shows up consistently in the defensive expenditure literature.

Of course, y^* does not remain constant, and (8) is usually not directly observable from actual avoidance behavior (y^* is not observable). To relate willingness to pay to changes in actual avoidance expenditures, equation (4) can be rearranged and substituted into equation (8) to show that:

$$\frac{\partial WTP}{\partial x'} > -p\frac{\partial a^*}{\partial x} = \textit{positive or negative value} \tag{9}$$

Thus, from (9), willingness to pay for an increase in basic quality from x to x+x' is always more than the negative of the change in avoidance expenditures that the household would actually make as a result of the basic quality improvement.[24]

Of course, it is entirely possible that avoidance expenditures increase as x increases (sign of (4) is positive), in which case changes in avoidance expenditures are an especially bad indicator of willingness to pay for improved water quality. Thus, while "it is possible to make tentative inferences about the <u>minimum</u> they are willing to pay to reduce this risk" (World Bank, 1993), this minimum willingness to

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[22] Note that equation (8) is just a more explicit form of equation (4) in Bartik (1988).

[23] In other words, the negative of the substitution effect in (4) is the same as willingness to pay for an increase in basic water quality from x to x+x' .

[24] This question could be empirically analyzed in a contingent valuation survey.

'pay' could actually involve a payment from the water company to the household receiving the improved quality. The precision of the relationship in (9) depends on the magnitude of the final quality effect in (4).

Of course, this discussion of avoidance behavior is essentially irrelevant if people in Moscow do not actually undertake avoidance measures to adjust their tap water quality prior to consumption. The follow section addresses this empirical question.

3. THE MOSCOW DRINKING WATER QUALITY SURVEY

A survey was completed during October 1996 to gather information on residents' opinions of the quality of cold water service to their apartments, any actions they take to alter the quality of the water consumed, simple information on expenditures associated with these actions, and general socioeconomic characteristics of the respondents.[25] As far as we know, this was the first formal survey designed and implemented to address water quality issues and avoidance behavior in Moscow and Russia.

There are two main water sources for Moscow, the Volga and Moscow rivers, and four water treatment and supply stations. The distribution networks from these four stations are essentially separate. The water sources have very different implications for water quality at the source. Both sources consist of reservoirs and rivers (streams). The Moscow-source reservoir is constructed relatively far from Moscow so that there is opportunity for water to be contaminated between the reservoir and the treatment facilities. The opposite situation occurs with the Volga source where the reservoir is located near the water treatment stations. Thus, water from the Northern and Eastern stations has had several months self-purification in the Uchinskoe reservoir (Moscow Committee of Nature Protection, 1993).

Using a telephone survey format, 1200 telephone numbers were drawn at random across Administrative Districts in Moscow.[26] These Administrative Districts of the city were sampled proportionately to reflect the two main sources of water for the city and the four main water treatment and supply facilities. An initial survey was developed in September 1996 and then pre-tested on a random sample from the 1200. After revising several questions, the final survey instrument was developed. In total, 615 respondents agreed to participate in the survey, including 268 respondents from Moskvoretsky drinking water source (hereafter called the Moscow source) and 347 respondents from the Volga drinking water source.[27] This distribution of about 44 percent from Moscow and 56 percent from Volga sources is the same as the actual distribution from the water supply network for each source. With respect to the four drinking water treatment stations, the distribution of respondents was: 114 for the Rublevo station (Moscow source), 154 for the Western station (Moscow source), 167 for the Northern station (Volga source), and 180 for the Eastern station (Volga source).

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[25] The survey was developed by the authors Alla Guzanova, and Dr. Guzanova's group at the Institute for Economic Forecasting implemented the survey. More details on the survey are discussed below.

[26] Dr. Alla Guzanova from the Institute for Economic Forecasting in Moscow led the survey team. Dr. Guzanova and her team (about 12 interviewers for this project) have substantial experience conducting socioeconomic surveys in Moscow, including longitudinal household surveys for the Urban Institute and the World Bank. There is about 97 percent coverage of telephones in apartments in Moscow.

[27] When a potential respondent, an adult living in the apartment, refused to participate in the survey, a new telephone number was drawn from the 1200 sample from the same Municipal District. In total, there were 63 refusals; overall sample size was 678 with about a 10 percent refusal rate.

The interviewers reported that most respondents were friendly, were willing to talk, and gave detailed answers. The interviews lasted twelve minutes on average. In the interviewers' opinions, the telephone survey worked 'as well as' their other in-home survey projects.

After an introduction to the survey, based on a pre-determined format written on the interviewer questionnaire booklet, the survey was organized into five main sections: avoidance measures; opinions of water quality; opinions of cold water supply (i.e. water quantity); apartment and family characteristics; and income. In the remainder of this section, we present and discuss basic summary information on the results of the survey of particular interest for this analysis.

3.1 Avoidance Measures

Four main types of avoidance measures were included in the survey: boiling, settling, filtering, and buying bottled water. Boiling and settling are customary and essentially no-cost options for households in Moscow.[28] Boiling is related mainly to concerns about bacteria, etc., while settling is done both for managing solids in water as well as improving taste and smell (e.g., chlorine). More recently, market availability of filters and bottled 'spring water' for general use, as opposed to mineral water, has increased. Filters and bottled water are two higher cost options.

Tables 1 - 4 report summary results of the survey for these avoidance measures. As expected, the lower cost alternatives are used more widely than higher cost options, with about 88 percent boiling water regularly (answers 1 and 2 in Table 1) due to health concerns, 33 percent settling water regularly before consumption (answers 1 and 2 in Table 2), about 23 percent filtering regularly (answers 1 and 2 in Table 3), and 13 percent purchasing spring water regularly for consumption purposes due to concerns about tap water quality (answers 1 and 2 in Table 4).[29] With a population of around 8.5-10 million people in Moscow, and extrapolating to the city level, these percentages add up to a substantial number of people undertaking avoidance measures in Moscow.

Given the nature of the survey as well as concerns that residents would not be able to answer more detailed questions, it was not feasible to ask more intricate questions such as how many liters per week are boiled and for how long or how many liters of bottled water are purchased, nor to ask details about filtering technology. Thus, it is probably best to think of this initial Moscow survey as a first empirical step; a step that shows substantial levels of avoidance measures being undertaken in Moscow.

It is necessary to be cautious when interpreting these answers, especially regarding boiling and buying bottled water. For example, there is the issue of 'joint production' when boiling water; that is people boil water because of health concerns but also for making tea and 'compote.' People can buy bottled water for 'taste' reasons as well as health reasons, and in many cases it is likely that people do it for both reasons. While the survey attempted to differentiate boiling and buying water 'due to health concerns,' it is possible that households are not really able to differentiate since they are intimately related. However, whether households boil water for tea or buy water for simple preference reasons, the end result is that they affect the final quality of the water that they consume.

[28] Stoves are mainly natural gas, and gas utility prices are low.

[29] Some people also report using 'traditional' water purification measures such as, for example, putting a silver spoon in water before consumption.

3.2 Opinions of Cold Water Quality

Table 5 summarizes Moscow residents' opinions of their cold water quality. Moscow residents report that they are generally satisfied with the quality of their cold water (about 88 percent from the Volga source and 82 percent from the Moscow source). While generally satisfied with cold water quality, residents generally have lower opinions of various characteristics of water. From Table 5, between 55 percent and 65 percent of residents report that water smells good, tastes good, and does not leave residue (calcium-like deposits) on dishes and sinks. These percentages are substantially lower in absolute terms than general satisfaction, which probably is related to a social or cultural expectation of what is considered acceptable water.[30]

The 6 percent difference in satisfaction rates between the two sources (88 percent for Volga and 82.2 percent for Moscow) is statistically significant at the 5 percent level using an approximate generalized likelihood ratio test.[31] The difference in clearness between the Moscow and Volga sources is also statistically significant at the 5 percent level. The responses for smell, taste, and residue are not statistically significant at the 5 percent level.[32]

While Table 5 provides results for the general opinion questions, Table 6 shows that there is some annual variation in water quality in Moscow, with the greatest annual variation being reported in terms of smell and taste. It is also noted here that the difference in opinions across the two sources is also statistically different for all characteristics reported in Table 6. Combining Tables 5 and 6, we conclude that opinions of quality are lower for the Moscow source, and there is more annual variation in the Moscow source as well.

3.4 Household and Apartment Characteristics

Table 7 summarizes self-reported total household income, which was designed to capture all types of formal and informal income. From the total sample of 615, 3 respondents did not answer this question. From Table 7, about 59 percent of households report income less than 1.5 million rubles per month (a little less than $300), about 25 percent report income between 1.5 and 2.5 million rubles per month (about $300 to $500), and a little over 16 percent report income levels over 2.5 million rubles. The last column in Table 7 shows that the income distribution obtained in this survey is very consistent with income information derived from a larger scale direct, in-home survey. This is another indication that the results obtained through this telephone survey format are reasonably good.

Over 90 percent of the sample live in buildings on the 12th floor or below built after 1955, which indicates the level of destruction during the Second World War and the level of reconstruction and growth after the war. Over 90 percent of families live in apartments with three or fewer rooms, with about 50 percent of the sample live in two room apartments. Over 65 percent of the sample pay 100,000 rubles or

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[30] Residents are generally content with cold water delivery, with just 6.5 percent of the sample dissatisfied with their tap water supply. Almost the complete sample has consistent 24-hour delivery, adequate pressure, etc. While not addressed in the survey, it is probably the case that residents without consistent cold water supply have plumbing problems in their building. Thus, the 'supply' problem is not really a problem with the water distribution network per se.

[31] We use the test specified in Theorem 8.4 of Larsen and Marx (1981, p. 335).

[32] As a side note, the best opinion of drinking water comes from residents receiving water from the Eastern water treatment station (Volga source), which is the only station in Moscow that uses ozonization instead of chlorination of the water.

less per month for their apartment including utility costs, which is a relatively small fraction of total household income.

In terms of demographics, over 80 percent of households have no children under 8 years old living in the apartment and about 68 percent of households have no children between 8 and 18 years old. About 17 percent of households have one child under 8 living in the apartment and 22 percent of households have one child between 8 and 18 years old. One household had more than two young children, while three households reported more than two older children. Over 52 percent of households included one or two pensioners, while about 47 percent included no pensioners.

In terms of education, over 90 percent of households contain at least one person who has completed at least secondary education, with over 54 percent of households containing persons with post-graduate training. Regarding the actual respondents to the survey, about 87 percent completed at least secondary education and about 39 percent had post-graduate training. About 76 percent of respondents were female, as might be expected with a telephone survey in Moscow. About 60 percent of respondents were 50 years old or less, with an average age of about 49 for the complete survey.[33]

About 13 percent of households reported plumbing problems that result in lost water in their apartments (either intensive drops, slight flow, or intensive flow), with some slight variation across regions of the city. Apparent water consumption in Moscow is high relative to other parts of Europe. For example, per capital daily water use is in the range of 200 liters per day in the European Union. Maizels and Isaev (1989) estimated that water 'consumption' in Moscow is in the range of 355 liters per day per capita, of which 115 liters per day are actually lost in the distribution system and perhaps 80 liters per day per capita are lost through leaks in buildings.[34]

4. LOGIT REGRESSION ANALYSIS OF AVOIDANCE BEHAVIOR

While the basic survey results reported in Section 3 support the notion that Moscow residents commonly use substantial levels of avoidance measures to adjust their water quality, the purpose of this section is to develop a better understanding of the factors that are related to such choices. While equation (2) provides a theoretical representation of this avoidance choice, the Moscow survey did not acquire data directly on exact quantities of avoidance measures used (liters of bottled water, liters of filtered water, etc.). The survey did ask questions in an ordered-categorical form (never, sometimes, most of the time, always). These categorical responses formed the basis for econometric analysis of the survey data.

Given the four choices for each question (always, most of the time, some of the time, never), a new binary variable was created for each measure, defined as 1 if the response was always or most of the time and 0 if sometimes or never. With this binary choice variable, a logistic (logit) regression framework was used to model the probability that a given respondent uses a specific avoidance measure (boil, settle, filter, and

[33] There were some initial concerns that only pensioners would be home to participate in a telephone survey. However, this was clearly not the case.

[34] A related topic for Moscow, as with other old cities, is the fact that sewerage and water lines were laid close to each other in several parts of the city. When sewerage lines break, as often happens with old pipes, the water lines can be contaminated.

buy bottled water).[35] Each of these four avoidance measures is not directly linked, so individual logit regressions for each measure are appropriate (there are no nesting or jointness issues).

With the cross-section survey data, basic prices for avoidance measures do not really vary for each households, so it is not possible to estimate the 'price' effect from (2). Higher income households are expected to undertake more avoidance for those measures that involve market expenditures such as filtering water and buying bottled water. For other measures, such as boiling water and settling water, there is essentially no cost involved for households.[36] From (4), one would expect more avoidance behavior when tap water quality is considered to be worse by residents.

Table 8 provides the parameter estimates for one basic model for each avoidance measure, where income, water supply station, and direct opinion on quality are included as explanatory variables. All explanatory variables in the model are zero/one variables. Thus, the base case represented by the constant is for low income households living in the Rublevo water supply region who consider their water quality to be good. The estimated parameter coefficients show the change in the probability of choosing an avoidance measure as this base case changes in terms of income (from low to medium and high), location (from Rublevo water supply station to the north, south, or east station), and overall opinion of water quality (from good quality to either OK or bad quality).

4.1 Income Effects

For purchasing bottled water and using filters, Table 8 shows that the parameters for income medium and income high are statistically significant at the 5 percent level, the parameters have a positive sign, and the parameter for income high is greater than that for income medium as would be expected by economic theory.[37]

For settling water, the income parameter is not statistically different from zero for both medium levels and of high levels of income. This result is also consistent with theory because settling involves essentially no cost in Moscow. With no expenditures, the income constraint does not matter for that avoidance measure in (1).

Regarding boiling, from Table 8, the parameter on the medium level of income is not significantly different from zero, as might be expected because boiling does not involve any real cost in Moscow so that the income constraint is not a binding factor in the choice of boiling. However, in Table 8, the parameter on the highest level of income (income H) is statistically significant at the 5 percent level and is

[35] In principle it is preferred to use an 'ordered' logit framework to handle the four possible answers to each avoidance question. However, for some answers to some of the questions, there are very few positive responses so that the degrees of freedom in the analysis are too small for statistical interpretation.

[36] Water and natural gas, the main cooking fuel, are provided at no marginal cost to households. There is some nominal time involved in boiling water, but it is almost zero given the gas stoves commonly used in apartments in Moscow. Time could be a much more serious issue in other parts of Russia and other parts of the world where heating water is a much more time consuming and costly activity. In this context, it could be appropriate to add a direct time constraint into problem (1) to consider labor and leisure choices as part of the analysis (see, e.g., Singh, Squire, and Strauss (1986) for examples of time-constrained models).

[37] The results for bottling can be used to look at the possible future market for bottled water in Moscow. For example, from the estimated regression, the probability of low income households in Rublevo region choosing bottled water is about 8 percent. This number increases to about 30 percent for high income households. Income growth over the next few years in Moscow could have a rather strong impact on the bottled water market.

negative. These empirical results indicate that boiling water has the characteristics of an 'inferior' good, and high income households tend to buy bottled water anyway, which reduces the need for boiling.[38]

4.2 Water Quality Effects (location or direct opinion)

As mentioned earlier, there are four water stations in Moscow (Rublevo, North, East, and West). In Table 8, North, East, and West are 0,1 dummy variables equal to 1 if the respondent receives water from that station. Also in Table 8, Qual OK and Qual Bad are 0,1 dummy variables. Based on the basic survey results, there is a strong relationship between water delivery station and overall opinion of quality. Thus, there is some strong correlation between location and opinion of quality, these variables are addressing the same issue in the survey, and correlation causes some multicolinearity problems in estimating a model with both location variables and the opinion of quality variable. In Table 8, as an indicator of basic water quality, water delivery station is used for the models of filtering and bottling, while direct opinion of quality is used for settling and boiling.

For bottling and filtering, the Rublevo station is the base case (i.e., it's excluded from the regression). Table 8 shows that these location variables are not statistically significant for purchasing bottled water. For bottled water, the highest cost option, income matters the most, which indicates that other factors beside water quality could be wrapped up in the decision to buy bottled water.

For filtering water, the North and East locations are statistically different from 0 at the 5 percent level and the signs on the parameters are negative, indicating that there is less filtering of water in the North and East locations as compared to Rublevo and West. Since North and East locations receive water from the Volga river while Rublevo and West locations receive water from the Moscow river, the estimates in Table 8 indicate that the structural difference in the water sources has some systematic impact on avoidance decisions. This result is also consistent with the summary survey results in Table 5 and 6, where residents receiving water from the Volga source (the North and East stations) are generally more satisfied with their water quality and report less annual variation than residents receiving water from the Moscow source.

Regarding settling choices, with quality good as the base case (i.e. dummy excluded from the regression), the dummy for quality OK is statistically different from zero at the 5 percent level and is positive. The parameter for quality bad, however, is not statistically different from zero. It seems plausible that households with OK water quality consider it reasonable to settle water to improve its quality, while households with bad water quality conclude that settling will have no benefit since the water is so bad. In the first case there is some perceived benefit of settling, while in the second case there is no perceived benefit of settling. Some other measure would be needed to improve quality.

Basic opinion of water quality is not related to boiling decisions. Of course, with over 88 percent of the sample boiling water (boil = 1 for the dependent variable in the logit model), and over 16 percent of the sample reporting high income, it is not surprising that only the parameter for high income is statistically significant in the logit regression.

5. CONCLUSIONS

Policy makers in Russia need a better understanding of health risks and least-cost ways for reducing such risks. In relation to public water supply and quality management, it is important to recognize the

[38] If boiling has essentially no cost, then the negative income effect on boiling must come from the underlying structure of the household water production function or the structure of household preferences. Either is possible.

importance of avoidance behavior for both the final level of risk (the difference between initial quality x and final quality y^* in the model in Section 2) and the least cost approaches to reducing such risks. In Moscow, where the Moscow Drinking Water Survey results show that a substantial portion of the sample boil, filter, and settle water as well as buying bottled water, it can be expected that final health risks y^* are substantially less than risks at the tap x. How much less remains an interesting empirical question for further exposure assessment research.

The issue of avoidance has strong implications for public policy. For example, it is entirely possible that the level of public health concern at risk level y^* may be acceptable, even though risks at x would be unacceptable. In this sense, public health concerns associated with tap water quality could be overstated in policy debates and city-level financial priority setting.

Similarly, least-cost approaches to improving water quality should consider both direct improvements in basic quality x as well as indirect improvements though the use of avoidance measures. For example, if there are concerns about biological contaminants in drinking water mainly during the spring rainy season (because fields are spread with manure before planting during the winter and spring), then the least-cost approach may be just to recommend publicly (e.g., radio, newspapers) that spring is the 'boiling' season.

The theoretical analysis in Section 2 provides a simple framework for understanding avoidance behavior and shows what key variables should be included in any empirical analysis of avoidance behavior. While not shown in previous literature on defensive expenditures, the theoretical analysis in Section 2 also shows that higher initial water quality always induces improved final quality of water consumed by households. This positive impact is reassuring from a public health perspective. Section 2 also shows that the actual change in avoidance expenditures induced by basic quality improvements are always less than what households would be willing to pay for better basic quality (see (9)). However, avoidance expenditures can increase when basic quality increases, which if used as a measure of willingness to pay would mean that people are willing to pay nothing for improved quality and would actually need to be paid to accept the quality improvement. Thus, for questions of improving quality, and expecting households to pay higher water charges as a result, direct valuation methods (i.e. contingent valuation) should be used. While not yet being conducted as far as we know, there are many opportunities to use such valuation methods in Russia to inform public decision making regarding water infrastructure improvements. For example, such work could be easily included in pre-feasibility studies of water projects to be supported by various water loans.

It is not possible, nor does it serve the purposes of this paper, to report and evaluate the large number of different types of regression models that could be investigated with the Moscow survey data. While the models in Table 8 include basic information on income and proxies for water quality (water station and direct opinion of quality), the models could be expanded to include other types of quality proxies (taste, smell, turbidity, seasonal variation of these characteristics, education, apartment characteristics, young children in the household, etc.). A simultaneous equation approach to modeling avoidance choices could also be considered. For example, it could be reasonable to consider first the decision to buy bottled water, then the decision to filter or boil, etc.. There remains substantial room for further empirical analysis with the existing data from the Moscow Drinking Water Quality Survey.

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Table 1. The Use of Boiling Water in Moscow (percentages)

Answer	total sample n= 615	Northern n=167	Eastern n=180	Rublevo n=114	Western n=154
1-always	80.7	77.2	80	88.6	79.3
2-rather often	7.8	10.8	8.9	0.9	8.4
3-seldom	4.2	3.0	6.1	2.6	4.5
4-never	7.3	9.0	5.0	7.9	7.8

Table 2. The Use of Settling Water in Moscow (percentages)

Answer	Total Sample	Northern	Eastern	Rublevo	Western
1-always	25.0	29.9	21.7	27.2	22.1
2-rather often	8.0	6.6	6.1	5.3	13.6
3-seldom	9.9	8.4	7.2	3.5	19.5
4-never	57.1	55.1	65.0	64.0	44.8

Table 3. The Use of Filtering Water in Moscow (percentages)

Answer	Total Sample	Northern	Eastern	Rublevo	Western
1-always	20.8	16.8	18.3	29.8	21.4
2-rather often	2.3	3.0	1.7	0.9	3.2
3-seldom	3.1	2.4	3.9	3.5	2.6
4-never	73.8	77.8	76.1	65.8	72.8

Table 4. The Use of Bottled Water in Moscow (percentages)

Answer	Total Sample	Northern	Eastern	Rublevo	Western
1-always	3.3	4.8	1.7	6.1	1.3
2-rather often	10.1	9.0	11.1	8.8	11.0
3-seldom	20.5	18.0	17.2	22.8	25.3
4-never	66.2	68.2	70.0	62.3	62.4

Table 5. Opinions of Water Quality

	Volga source (%)	Moscow source (%)
normal clearness	85.6	76.8
good smell	61.5	55.7
good taste	57.2	54.6
no residue	63.9	57.9
normal color	82.1	82.2
general satisfaction	88.0	82.2

Table 6. Water Quality Characteristics Vary Significantly During the Year

	Volga source (%)	Moscow source (%)
clearness	3.2	8.6
smell	11.2	28.7
taste	8.9	16.1
residue	2.7	8.4
color	2.7	7.5

Table 7. Reported Monthly Total Household Income

Total Monthly Income (million roubles)	**total sample** %	**Northern station** %	**Eastern station** %	**Rublevo station** %	**Western station** %	**In-Home Survey**
1-less than 1.5	58.9	55	60.6	68.4	53.9	59.0
2-1.5-2.5	24.2	24.6	22.8	17.5	30.5	24.5
3-more than 2.5	16.4	19.8	16.6	14.1	14.3	15.6
4-no answer	0.5	0.6	0.0	0.0	1.3	0.09

*Note:*The last column, 'in-home survey,' is the results of a recent 2200 direct, in-home survey conducted by the survey team as part of the Moscow Longitudinal Household Survey, 1992-1996, fourth round, January 1996.

Table 8. Binomial Logit Regressions for Use of Avoidance Measures

n = 612	SETTLE		FILTER		BOTTLE		BOIL	
	COEFFICIENT	**z**	**COEFFICIENT**	**z**	**COEFFICIENT**	**z**	**COEFFICIENT**	**z**
CONSTANT	-0.85	-5.8	-1.09	-4.9	-2.41	-7.7	2.19	2.9
INCOME M	-0.09	-0.5	0.71	3.1	1.44	4.8	-0.05	-0.2
INCOME H	-0.17	-0.7	0.92	3.6	1.66	5.2	-0.94	-3.1
NORTH			-0.71	-2.5	-0.37	-1.0		
EAST			-0.66	-2.3	-0.33	-0.9		
WEST			-0.39	-1.4	-0.43	-1.1		
QUAL OK	0.65	3.2					0.54	1.6
QUAL BAD	-0.08	-0.4					-0.26	-0.9

Notes: 1 = use measure all the time or regularly, 0 = use measure never or seldom.
The variable z has a normal distribution with a mean of zero and a variance of one.